Amendments to the Specification

Please replace the paragraph on Page 4, lines 5-18 with the following replacement paragraph:

Recently, increased research activity is directed towards developing spectrometers for sensing applications and for wavelength division multiplexing (WDM) in optical communication; however, a simple low cost solution with a totally integrated opto-electronic part using standard technologies is still lacking. A variety of spectrometric probes for in situ measurement are known in the art. U.S. Patent No 5,712,710 for example, describes a probe for use in measuring the concentration of a specific metal ion dissolved in liquid. The device suffers from known problems of probe miniaturization. Either the bandwidth [[og]] of the spectrometer is narrow to accommodate a small probe size, the quality of the spectral imaging is poor, or the optical processing components are large and costly.[[,]]The device comprises a hand-held processing unit coupled to the probe. The processing unit is programmed to calculate and display the concentration of a specific material. In this probe, neither the photodetector nor the processing unit are integrated with the light diffraction structure. Further, the use of poor resolution in imaging the spectrum is unacceptable for most applications when using such a probe.

Please replace the paragraph beginning on Page 11, line 4 and continuing to Page 12, line 12 with the following replacement paragraph:

The following notation is used for the description of the invention:

λ - wavelength; $\lambda \in [\lambda_{\min}, \lambda_{\max}]$;

N - number of data acquired by the spectrometric apparatus;

$\Delta\lambda$ - step of wavelength discretization; $\Delta\lambda = (\lambda_{\max} - \lambda_{\min})/(N-1)$;

λ_n - n-th datum acquired by the spectrometric apparatus; $\lambda_n = \lambda_{\min} + (n-1)\Delta\lambda$ for $n = 1,\ldots,N$;

$x(\lambda)$ - real spectrum of a sample under study;

$\mathbf{l}$ - vector of the positions of peaks the spectrum $x(\lambda)$ is composed of; $\mathbf{l} = [l_1\ l_2\ \ldots\ l_K]^T$;

[[$\mathbf{l}$]] $\hat{\mathbf{l}}$ - an estimate of $\mathbf{l}$;

a - vector of magnitudes of peaks the spectrum $x(\lambda)$ is composed of; $\mathbf{a} = [a_1\ a_2\ \dots\ a_K]^T$;

[[$\mathbf{a}$]] $\hat{\mathbf{a}}$ - an estimate of $\mathbf{a}$;

$s(\lambda;\mathbf{l},\mathbf{a})$ - an idealized spectrum of a sample under study, assumed to have the form:

$$s(\lambda;\mathbf{l},\mathbf{a}) = \sum_{k=1}^{K} a_k v_s(\lambda, l_k)$$

where $v_s(\lambda, l)$ is an isolated, normalized peak in $s(\lambda;\mathbf{l},\mathbf{a})$, whose maximum is located at $\lambda = l$; $\int_{-\infty}^{+\infty} v_s(\lambda, l)\, d\lambda = 1$ for $l \in [\lambda_{\min}, \lambda_{\max}]$;

$\{\tilde{y}_n\}$ - spectrometric data representative of $x(\lambda)$, acquired by means of the spectrometric apparatus; $\{\tilde{y}_n\} \equiv \{\tilde{y}_n \mid n = 1,\dots,N\}$;

$x^{cal}(\lambda)$ - real spectrum of a sample used for calibration of the spectrometric apparatus;

$s(\lambda;\mathbf{l}^{cal},\mathbf{a}^{cal})$ - an idealized spectrum of the sample used for calibration of the spectrometric apparatus;

$\{\tilde{y}_n^{cal}\}$ - spectrometric data, representative of $x^{cal}(\lambda)$ used for calibration of the spectrometric apparatus; $\{\tilde{y}_n^{cal}\} \equiv \{\tilde{y}_n^{cal} \mid n = 1,\dots,N^{cal}\}$;

G - an operator (algorithm) of projection mapping the idealized spectrum $s(\lambda;\mathbf{l},\mathbf{a})$ into the space of the data:

$$\cancel{\{y_n^{\infty}\} = G[s(\lambda;l,a);p_G)\}}\ \underline{\{\hat{y}_n\} = \mathrm{G}\left[s(\lambda;\mathbf{l},\mathbf{a});\mathbf{p}_\mathrm{G}\right]}$$

where $\mathbf{p}_\mathrm{G}$ is a vector or matrix of the parameters of the operator G, to be determined during calibration of the spectrometric apparatus; $\mathbf{p}_\mathrm{G} = [p_{\mathrm{G},1}\ p_{\mathrm{G},2}\ \dots]^T$ or:

$$\cancel{p_G = \begin{bmatrix} p_{G_{1,1}} & p_{G_{1,2}} & symbol \\ p_{G_{2,1}} & p_{G_{2,2}} & symbol \\ symbol & symbol & symbol \end{bmatrix}}\ \underline{\mathbf{p}_\mathrm{G} = \begin{bmatrix} p_{\mathrm{G},1,1} & p_{\mathrm{G},1,2} & \cdots \\ p_{\mathrm{G},2,1} & p_{\mathrm{G},2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}}$$

R - an operator of reconstruction such as a generalized deconvolution operator for transforming the data $\{\tilde{y}_n\}$ into an estimate [[$s^*({}^*\lambda)$]] $\underline{\hat{s}(\lambda)}$ of $s(\lambda;\mathbf{l},\mathbf{a})$:

~~$s^{*}(\lambda) = R[\{\tilde{y}_n\}; p_R]$~~ $\hat{s}(\lambda) = \mathrm{R}\left[\{\tilde{y}_n\}; \mathbf{p}_\mathrm{R}\right]$

where $\mathbf{p}_\mathrm{R} = \left[p_{\mathrm{R},1}\, p_{\mathrm{R},2} \ldots\right]^T$ are parameters of the operator R including regularization parameters, the parameters determined during calibration of the spectrometric apparatus.

Please replace the paragraph on Page 16, lines 17-26 with the following replacement paragraph:

Fig. 4 illustrates the results of an experiment showing the practical gain in the quality of the measurement result obtained using the invention. In this figure

x(λ) represents data acquired by means of the reference spectrophotometer ANRITSU (MV02-Series Optical Spectrum Analyzer) set to the resolution of 0.1nm (which is not available in today's integrated spectrometers);

$\tilde{y}(\lambda)$ is a raw measurement acquired by means of a same reference instrument set to a resolution of 5nm - a typical resolution of integrated spectrometers without internal specialized digital signal processors; and,

[[~~$x^{*}(\lambda)$~~]] $\hat{x}(\lambda)$ is an estimate of a spectrum, whose resolution is 0.1nm, obtained using digital signal processing according to the invention.

Please replace the paragraph beginning on Page 16, line 27 and continuing to Page 17, line 9, with the following replacement paragraph:

As is evident from a review of Fig. 4, a low resolution $\tilde{y}(\lambda)$ is enhanced to form an excellent approximation of the spectrum measured using a higher resolution spectrometer. Comparison of the signals $x(\lambda)$, $\tilde{y}(\lambda)$ and [[~~$x^{*}(\lambda)$~~]] $\hat{x}(\lambda)$ gives an idea of practical gains obtained using the invention - the gain in resolution shown is of the order of 10. Therefore, the experiment clearly demonstrates that using a low-resolution dispersive element and a DSP, results are typical of a spectrometer having significantly better resolution. Since size of spectrometers is at least partially related to resolution, a device according to the present invention permits spectrometers of significantly reduced size for use in similar applications. Of

course, the reduced size and cost of the device permit many new applications heretofore prohibited by size, cost, and/or resolution of prior art spectrometers.

Please replace the paragraph on Page 19, lines 9-23 with the following replacement paragraph:

Fig.6 illustrates the results of an experiment showing the effectiveness of the IISS/T designed according to the invention. In this figure:

$x(\lambda)$ represents the data acquired by means of a reference spectrometer CARY-3 (Varian) set to a resolution of 0.2nm - a resolution not commonly available in prior art integrated spectrometers;

$\underline{\tilde{y}(\lambda)}$ is a measurement result at the output of the model of the spectrometric transducer of the IISS/T, with 1.5nm resolution; and,

[[$x^*(^*\lambda)$]] $\underline{\hat{x}(\lambda)}$ is an estimate of the spectrum $x(\lambda)$, whose resolution obtained after digital signal processing is approximately 0.1nm. This is the resolution obtainable at the output of the IISS/T, proposed according to the invention, satisfying the users' requirements for many practical applications. An enhancement of about 10 times the resolution is achieved. Of course, as spectral enhancement increases to for example 40 or 60 times the resolution of the transducer, it is expected that errors in estimation will also increase. This should be evaluated on an application by application basis to determine applicability and degree of miniaturization of the invention for a particular application.

Please replace the paragraph on Page 23, lines 1-6 with the following replacement paragraph:

In accordance with the above general functional requirements and referring to Figs. 11a through 11d, the method comprises the following steps:

- calibration of a spectrometer (the sub-procedure ISD_cal),
- reconstruction of a spectrum $s(\lambda;\mathbf{l},\mathbf{a})$ (the sub-procedure ISD_rec),

estimation of parameters $\mathbf{l}$ and $\mathbf{a}$ on the basis of an estimate [[$s^*(^*\lambda)$]] $\underline{\hat{s}(\lambda)}$ of $s(\lambda;\mathbf{l},\mathbf{a})$ (the sub-procedure ISD_est).

Please replace the paragraph on Page 24, lines 6-16 with the following replacement paragraph:

The sub-procedure ISD_est comprises the following steps:

a) estimating positions $\mathbf{l}$ of peaks within a spectrum on the basis of the estimate ~~[[$s^{*}({}^{*}\lambda)$]]~~ $\underline{\hat{s}(\lambda)}$ of $s(\lambda;\mathbf{l},\mathbf{a})$ by means of a maximum-detection algorithm;

b) estimating magnitudes $\mathbf{a}$ of the peaks, by means of a curve fitting algorithm using one of the following methods:

- the data $\{\tilde{y}_n\}$, $v_s(\lambda,l)$, the operator G with parameters $\mathrm{p_G}$, and the estimate $\hat{\mathbf{l}}$;
- the estimate ~~[[$s^{*}({}^{*}\lambda)$]]~~ $\underline{\hat{s}(\lambda)}$, $v_s(\lambda,l)$, and the estimate $\hat{\mathbf{l}}$.

c) iteratively correcting the estimates of the parameters of peaks obtained in (a) and (b); adapting the results of parameter estimation in accordance with user requirements, such as transformation of parameters into some pre-defined parameters of an analyzed substance.

Please replace the paragraph on Page 26, lines 2-12 with the following replacement paragraph:

The chosen operator of projection, for mapping an idealized spectrum $s(\lambda;\mathbf{l},\mathbf{a})$ into the data space

$$\cancel{\{y_n^{\infty}\}=G[s(\lambda;l,a);p_G]}\ \underline{\{\hat{y}_n\}=\mathrm{G}\left[s(\lambda;\mathbf{l},\mathbf{a});\mathrm{p_G}\right]}$$

is defined by the following operations:

$$x(\lambda)=\exp\left[\int_{-\infty}^{+\infty} g_{sx}(\lambda-\lambda')\ \ln[s(\lambda';\mathbf{l},\mathbf{a})]\ d\lambda'\right]$$

$$y(\lambda)=\int_{-\infty}^{+\infty} g_{xy}(\lambda-\lambda')\ x(\lambda')\ d\lambda'$$

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$$\cancel{y_n^{\sim} = y(\lambda_n) \text{ for } n = 1,\ldots,N} \quad \underline{\hat{y}_n = y(\lambda_n) \text{ for } n = 1,\ldots,N}$$

The function $g_{xy}(\lambda)$ is estimated to have the form of the Gauss function:

$$g_{xy}(\lambda) = \frac{1}{\sqrt{2\pi}\sigma_{xy}} \exp\left(-\frac{\lambda^2}{2\sigma_{xy}^2}\right)$$

Consequently, the vector of the parameters p_G of the operator G contains discrete values of $g_{ex}(\lambda)$ and parameter σ_{xy}.

Please replace the paragraph beginning on Page 26, line 13 and continuing to Page 27, line 2 with the following replacement paragraph:

The chosen operator of reconstruction, for transforming the data $\{\tilde{y}_n\}$ into an estimate [[$s^*(^*\lambda)$]] $\underline{\hat{s}(\lambda)}$ of $s(\lambda;1,a)$,

$$\cancel{s^*(^*\lambda) = R[\{\tilde{y}_n\};p_R]} \quad \underline{\hat{s}(\lambda) = R\left[\{\tilde{y}_n\};p_R\right]},$$

is specified by the following steps:

a discrete estimate [[$\{x_n^{\sim}\}$]] $\underline{\{\hat{x}_n\}}$ of $x(\lambda)$ is found by means of a rational filter applied to the data $\{\tilde{y}_n\}$; and,

an estimate [[$s^*(^*\lambda)$]] $\underline{\hat{s}(\lambda)}$ of $s(\lambda;1,a)$ is computed using a spline-based Kalman filter applied to [[$\{x_n^{\sim}\}$]] $\underline{\{\hat{x}_n\}}$.

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Please replace the paragraph on Page 27, lines 15-21 with the following replacement paragraph:

The exemplary results of spectrophotometric data resolution augmentation obtained by means of this exemplary method are shown in Fig.15a, Fig.15b and Fig.16. The estimates of test spectrum parameters obtained by means of the present method, are as follows:

the vector of the positions of peaks:

$$\cancel{l^{**} = [386\ 390.8\ 395.1\ 410.8\ 417.2\ 421.4\ 451.1\ 468\ 473.1\ 479\ 485\ 492.2]^T}$$

$$\underline{\hat{\mathbf{l}} = [386\ 390.8\ 395.1\ 410.8\ 417.2\ 421.4\ 451.1\ 468\ 473.1\ 479\ 485\ 492.2]^T}$$

the vector of the magnitudes of peaks:

$$\cancel{a^{**} = [.1276\ .0738\ .0376\ .0243\ .6932\ .235\ 1.3142\ .1729\ .2593\ .1239\ .4937\ .079]^T}$$

$$\underline{\hat{\mathbf{a}} = [.1276\ .0738\ .0376\ .0243\ .6932\ .235\ 1.3142\ .1729\ .2593\ .1239\ .4937\ .079]^T}$$

Please replace the paragraph beginning on Page 29, line 7 and continuing to Page 30, line 2 with the following replacement paragraph:

The corresponding operators **G** have the following forms:

a) the operator corresponding to the stationary linear model:

$$\cancel{y_n^{**} = \sum_\nu p_{Gn,\nu} \int_{\lambda_\nu}^{\lambda_{\nu+1}} s(\lambda'; l, a) d\lambda'} \quad \underline{\hat{y}_n = \sum_\nu p_{\mathrm{G}\,n,\nu} \int_{\lambda_\nu}^{\lambda_{\nu+1}} s(\lambda'; \mathbf{l}, \mathbf{a})\, d\lambda'}$$

where $p_{\mathrm{G},\nu} = g\left(\frac{\lambda_{\nu+1} + \lambda_\nu}{2}\right) \Delta\lambda;$

b) the operator corresponding to the non-stationary linear model:

$$\cancel{y_n^{**} = \sum_\nu p_{Gn,\nu} \int_{\lambda_\nu}^{\lambda_{\nu+1}} s(\lambda'; l, a) d\lambda'} \quad \underline{\hat{y}_n = \sum_\nu p_{\mathrm{G}\,n,\nu} \int_{\lambda_\nu}^{\lambda_{\nu+1}} s(\lambda'; \mathbf{l}, \mathbf{a})\, d\lambda'}$$

where $p_{G\,n,v} = g\left(\lambda_n, \frac{\lambda_{v+1}+\lambda_v}{2}\right)\Delta\lambda$; and,

c) the operator corresponding to the exemplary non-linear models:

$$\cancel{y_n^{**} = \sum_v p_{Gn,v} \int_{\lambda_v}^{\lambda_{v+1}} F_s\left[s(\lambda';l,a)\right]d\lambda'} \quad \underline{\hat{y}_n = \sum_v p_{G\,n,v} \int_{\lambda_v}^{\lambda_{v+1}} F_s\left[s(\lambda';\mathbf{l},\mathbf{a})\right] d\lambda'}$$

$$\cancel{y_n^{**} = F_y\left[\sum_v p_{Gn,v} \int_{\lambda_v}^{\lambda_{v+1}} F_s\left[s(\lambda';l,a)\right]d\lambda'\right]} \quad \underline{\hat{y}_n = F_y\left[\sum_v p_{G\,n,v} \int_{\lambda_v}^{\lambda_{v+1}} F_s\left[s(\lambda';\mathbf{l},\mathbf{a})\right] d\lambda'\right]}$$

where $p_{G\,n,v} = g\left(\lambda_n, \frac{\lambda_{v+1}+\lambda_v}{2}\right)\Delta\lambda$.

Please replace the paragraph beginning on Page 32, line 1 and continuing to Page 33, line 1 with the following replacement paragraph:

Optionally, at least one of the following methods is used for estimation of magnitudes $\mathbf{a}$ of peaks, given the estimates $\hat{\mathbf{l}}$ of their positions $\mathbf{l}$:

$$\cancel{a^{**} = \arg_a \inf\left\{\left\|\{\tilde{y}_n\} - G\left[s(\lambda;l^{**},a), p_G\right]\right\|_q \mid a \in A\right\}}$$

$$\underline{\hat{\mathbf{a}} = \arg_{\mathbf{a}} \inf\left\{\left\|\{\tilde{y}_n\} - \mathrm{G}\left[s(\lambda;\hat{\mathbf{l}},\mathbf{a}); p_{\mathrm{G}}\right]\right\|_q \mid \mathbf{a} \in \mathbf{A}\right\}} \text{; and}$$

$$\cancel{a^{**} = \arg_a \inf\left\{\left\|s^{*}({}^{*}\lambda) - s(\lambda;l^{**},a)\right\|_q \mid a \in A\right\}}$$

$$\underline{\hat{\mathbf{a}} = \arg_{\mathbf{a}} \inf\left\{\left\|\hat{s}(\lambda) - s(\lambda;\hat{\mathbf{l}},\mathbf{a})\right\|_q \mid \mathbf{a} \in \mathbf{A}\right\}}$$

with $\mathbf{A}$ - being a set of feasible solutions; options: q=2 and $\mathbf{A} \subset \mathrm{R}^k$; q=∞ and $\mathbf{A} \subset \mathrm{R}^k$; q=2 and $\mathbf{A} \subset \mathrm{R}_+^k$; q=∞ and $\mathbf{A} \subset \mathrm{R}_+^k$. Some examples of algorithmic solutions are given in Deming S. N., Morgan S. L.: *Experimental Design : A Chemometric Approach*, Elsevier 1987; Fraser R. D. B.,

Suzuki E.: "Biological Applications". In: *Spectral Analysis - Methods and Techniques (ed by J. A. Balckburn)*, M. Dekker, 1970, pp. 171-211; Fister III J. C., Harris J. M.: "Multidimensional Least Squares Resolution of Excited State Raman Spectra", *Anal. Chem.*, Vol. 67, No. 4, 1995b, pp.701-709 ; Fister III J. C., Harris J. M.: "Multidimensional Least Squares Resolution of Raman Spectra from Intermediates in Photochemical Reactions", *Anal. Chem.*, Vol. 67, No. 8, 1995a, pp.1361-1370; Goodman K. J., Brenna T.: "Curve Fitting for Restoration of Accuracy of Overlapping Peaks in Gas Chromatography / Combustion Ratio Mass Spectrometry", *Anal. Chem.*, Vol.66, No. 8, 1994, pp. 1294-1301; Miekina *et al.* "Incorporation of the Positivity Constraint into a Tikhonov-method-based Algorithm of Measurand Reconstruction". *Proc. IMEKO-TC1&TC7 Colloquium (London, UK, Sept. 8-10, 1993)*, pp. 299-304 and so forth. A particularly effective solution of the above optimization problem is based on a non-stationary Kalman filter or an adaptive LMS algorithm as described in Ben Slima M., Szczecinski L., Massicotte D., Morawski R. Z., Barwicz A.: "Algorithmic Specification of a Specialized Processor for Spectrometric Applictions", *Proc. IEEE Instrum. & Meas. Technology Conf. (Ottawa, Canada, May 19-21, 1997)*, pp. 90-95 and in Ben Slima M., Morawski R. Z., Barwicz A.: "Kalman-filter-based Algorithms of Spectrophotometric Data Correction - Part II: Use of Splines for Approximation of Spectra", *IEEE Trans. Instrum. & Meas.*, Vol. 46, No. 3, June 1997, pp. 685-689.

Please replace the paragraph on Page 33, lines 2-9 with the following replacement paragraph:

Optionally, methods for estimation of the magnitudes **a** are used for iterative correction of estimates of magnitudes **a** and positions **l** of the peaks. Known methods include the following :

$$\cancel{l^{**} = \arg_l \inf\left\{\left\|\{\tilde{y}_n\} - G\left[s(\lambda; l, a^{**}); p_G\right]\right\|_q \mid l \in L\right\}}$$

$$\underline{\hat{\mathbf{l}} = \arg_{\mathbf{l}} \inf\left\{\left\|\{\tilde{y}_n\} - \mathrm{G}\left[s(\lambda; \mathbf{l}, \hat{\mathbf{a}}); \mathrm{p_G}\right]\right\|_q \mid \mathbf{l} \in \mathrm{L}\right\}}$$

and,

$$\cancel{l^{**} = \arg_l \inf\left\{\left\|s^*({}^*\lambda) - s(\lambda; l, a^{**})\right\|_q \mid l \in L\right\}}$$

$$\underline{\hat{l} = \arg_l \inf\left\{\left\|\hat{s}(\lambda) - s(\lambda; l, \hat{a})\right\|_q \mid l \in L\right\}}$$

with L being a set of feasible solutions; options: q=2 and $L \subset R^k$; q=∞ and $L \subset R^k$; q=2 and $L \subset R^k_+$; q=∞ and $L \subset R^k_+$.

Please replace the paragraph on Page 33, lines 10-20 with the following replacement paragraph:

According to the method set out above, the data are pre-processed. The pre-processing is performed according to known techniques and for known purposes with relation to the methods selected for augmenting resolution of the spectral data and the sensor with which the pre-processing is used. Optionally, one of the following methods is used for normalization of the data:

a) the linear or nonlinear transformation of the λ-axis, aimed at diminishing the non-stationarity effects in the data;
b) the linear or nonlinear transformation of the y-axis, aimed at diminishing the non-linearity effects in the data;
c) the linear or nonlinear transformation of the λ-axis and y-axis, aimed at diminishing the non-stationarity and non-linearity effects in the data.